Effects of Personal Equipment on Psycho-Physiological Capabilities: A New Approach to Performance Diagnostics in Armament Projects

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ABSTRACT

In modern armed forces the technical progress of the last decades has enhanced numerous different capabilities of soldiers. Despite new and efficient technologies individual physical and mental abilities are still essential and often the limiting factors for many military tasks. For that reason some recent innovations led to unexpected new problems: Instead of enhancing they might reduce performance. For example dismounted infantry in particular have to carry more and more equipment in order to improve their survivability and capabilities. However, current combat loads, combined with environmental conditions and mission requirements hinder mobility and affect endurance in combat operations. These demands will quickly exhaust even physically fit soldiers. Therefore future programmes must pay more attention to human factors: New equipment should support and not impair the human potential of the soldier in his fundamental functions to see, to hear, to communicate, to move, to fire and to survive.

In order to prevent time and money wasting abortive developments it is essential to review the different development stages - particularly concerning the human factors - from the beginning to the end of the project. Currently no standardized performance tests are available that simultaneously quantify the effects of personal equipment on both physical and mental capabilities during characteristic military mission stresses.

Therefore the aim of our study was to develop a lab-based performance test battery that meets these requirements. For this purpose our approach includes the following steps:

1. *Collection and analysis of reference data in field tests in realistic combat missions (e. g. MOUT), subsequent identification and definition of critical task demands.*
2. *Development of a specific laboratory test reflecting the physical requirements of characteristic mission tasks (e. g. patrol, attack, etc.) based on the obtained results of the field tests.*
3. *Integration of various psychological test procedures demanding different mental qualities (perception, cognition, short-term memory).*

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14. ABSTRACT
In modern armed forces the technical progress of the last decades has enhanced numerous different capabilities of soldiers. Despite new and efficient technologies individual physical and mental abilities are still essential and often the limiting factors for many military tasks. For that reason some recent innovations led to unexpected new problems: Instead of enhancing they might reduce performance. For example dismounted infantry in particular have to carry more and more equipment in order to improve their survivability and capabilities. However, current combat loads, combined with environmental conditions and mission requirements hinder mobility and affect endurance in combat operations. These demands will quickly exhaust even physically fit soldiers. Therefore future programmes must pay more attention to human factors: New equipment should support and not impair the human potential of the soldier in his fundamental functions to see, to hear, to communicate, to move, to fire and to survive.

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The resulting complex performance battery tests both physical and mental capabilities under standardized conditions. If required the tests can also be performed also under special environmental conditions like heat, cold or height in a simulation chamber. This modular test system might be used for the evaluation of the efficiency of armament projects in future.

1.0 INTRODUCTION

Since nearly two decades the armed forces of many NATO member countries are engaged in a number of conflicts. These missions differ considerably from the Cold War scenarios and pose a wider variety of demands (Dean 2004, Krulak 1999). It was recognised early that in spite of new high tech weapon systems the infantry will still be of outstanding importance for the success of military operations. Therefore, in 1996, some NATO nations decided to develop modular systems for the dismounted soldier to enhance mobility, command and control, sustainability, survivability and lethality (NATO Army Armaments Group 1996a and 1996b). Simultaneously, new technologies were supposed to protect him against physiological stresses such as heat build-up or fatigue and mental stresses such as information overload. But regardless of these guidelines, soldiers today have to carry more personal equipment and electronic devices than ever before (Dean 2004, Knapik 2004). However, current combat loads, combined with environmental conditions and mission requirements affect their capabilities in action and will quickly exhaust even physically fit soldiers. In addition, the use of complex miniaturised electronic systems (command, control, communication, computers and intelligence (C4I)) may divert attention or critically reduce cognitive capacity in action and lead to fatal errors. Despite all of new and efficient technologies the individual physical and mental abilities are still essential and often the limiting factors for many military tasks (Bilzon et al. 2001, Haisman 1988, Knapik 1990 and 2000, Lyons et al. 2005, Rohde et al. 2007, RTO 2001). Therefore future programmes may not only focus on technical progress but also must pay more attention to human factors: New equipment should support and not impair the human potential of the soldier in his fundamental functions to see, to hear, to communicate, to move, to fire and to survive.

In order to prevent time and money wasting abortive developments our department is involved in the new German Future Soldier System Programme ("Infanterist der Zukunft – Expanded System") to review the different development stages particularly concerning the human factors from the beginning to the end of the project (BMVg 2004). Initially, no standardized performance tests were available to simultaneously quantify the effects of personal equipment on both physical and mental capabilities during characteristic military mission stresses (Eßfeld 2007 and 2008).

Thus, aim of our study was to develop a lab-based performance test battery that meets these requirements. To achieve this, our approach includes the following steps:

2.0 FIELD TEST

In a first step we collected reference data of characteristic combat missions in field tests in order to quantify the strains and to obtain a profile of the demands. To achieve this we developed in co-operation with the Infantry School, the Mountain and Winter Combat School and the Armor School various realistic scenarios with representative action tasks:

- Infantry School: "MOUT" and "Three Block War"
- Mountain and Winter Combat School: Foot march
- Armor School (Mechanized Infantry): Barrier operations, assault phase

Figure 1: Analysed tasks: Infantry School - MOUT (above left); Armor School - Assault phase (above right); Mountain and Winter Combat School - Foot march (below).

In order to obtain the full scope of the demands and the capabilities of the soldiers we performed a broad variety of tests. Following baseline values were taken of every participant one day before exercise:

- Anthropometric measurements: height, weight, BMI, body fat, waist to hip ratio
- Muscle strength (maximum voluntary contraction): elbow flexor, hand grip, knee extensor, trunk extensor and flexor
- Postural control
- Manual coordination
- Scaled Questionnaires: Lifestyle, health, job, psychological state, ratings of perceived exertion

Figure 2: Data collection in the field: Strength measurements (elbow flexor and trunk flexor) after MOUT exercise (left); Blood lactate concentration, oxygen uptake, ventilation, heart rate during mountain march (right)

On the day of the exercise we repeated the tests before and after the action task except the anthropometric measurements in order to assess the influence of the strains on these parameters. During action we obtained:

- Heart rate tracings
- Time courses of oxygen uptake, ventilation
- Blood lactate concentrations
- Loads and distances

The operations differ significantly concerning the profiles of physical and mental demands depending on type of movement, intensity, duration, distances, loads, equipment, mission and environmental conditions. After analysis of the complete data material we indentified and defined the characteristic physical and mental demands with the support of experienced infantry-men.

3.0 LABORATORY TEST BATTERY

Based on the obtained results we developed a specific lab-based test battery that reflects both the physical and the mental requirements of characteristic infantry mission tasks.

3.1 Physical requirements

To reproduce the physical requirements under standardized conditions in a laboratory, a performance test on a treadmill is used. The collected parameters correspond to the field tests and are complemented by modified questionnaires (e. g. equipment comfort).

The physical demands consist of two factors: Load (uniform and equipment) and movement. The factor load depends on the uniform worn and equipment carried. The factor movement is divided into a lower intensity and a high intensity part. The first low intensity part consists of 30 min marching with 3 km/h at 0 % grade and 30 min marching with 3 km/h at 10 % grade, mimicking a patrol. The second high intensity part includes five 35 m (12 s) sprints at a speed of 14.5 km/h at 0 % grade, four 35 m (12 s) sprints with 14.5 km/h at 10 % grade and one final sprint at a speed of 14.5 km/h at 10 % grade until exhaustion. As in a live attack or assault phase (fire and maneuver) there are only short breaks (15 s) between the sprints 1 – 5 and 6 – 10. Between sprint 5 and 6 the interruption lasts 60 s. Every test is carried out until exhaustion of the participant and is followed by ten minutes of recovery. The entire sequence of the Load-March-Attack-Assault Test (LMAA-Test) is shown in table 1 and figure 3.

Pre-Performance-Test		Anthropometric measurements, questionnaire (life style, health, job, etc.), muscle strength, postural control and manual coordination					
LMAA-Test Phase		Time (s)	Velocity (km/h)	Grade (%)	Lactate [mmol*l^{-1}]	Heart rate (min^{-1})	VO_2 (l*min^{-1})
Base		120	0	0	X	Continuously (beat-to-beat)	Continuously (breath-by-breath)
March 1 “Plain”		1800	3.0	0	-		
Interruption		120	0	0	X		
March 2 “Mountain”		1800	3.0	10	-		
Interruption		180	0	0	2 X (beginning / end)		
Sprint “Plain”	Sprint 1 (incl. break)	27	14.5	0	-		
	Sprint 2 (incl. break)	27	14.5	0	-		
	Sprint 3 (incl. break)	27	14.5	0	-		
	Sprint 4 (incl. break)	27	14.5	0	-		
	Sprint 5	12	14.5	0	-		
Interruption		60	0	0	X		
Sprint “Mountain”	Sprint 6 (incl. break)	27	14.5	10	-		
	Sprint 7 (incl. break)	27	14.5	10	-		
	Sprint 8 (incl. break)	27	14.5	10	-		
	Sprint 9 (incl. break)	27	14.5	10	-		
	Sprint 10	500	14.5	10	-		
Exhaustion / Abandonment		0	0	0	X		
Recovery		60	0	0	X		
		120	0	0	X		
		120	0	0	X		
		120	0	0	X		
		120	0	0	X		
		60	0	0	-		
After-Performance-Test		Questionnaire (perceived exertion, equipment comfort), muscle strength, postural control and manual coordination					

Table 1: Detailed sequence of the Load-March-Attack-Assault Test (LMAA-Test)

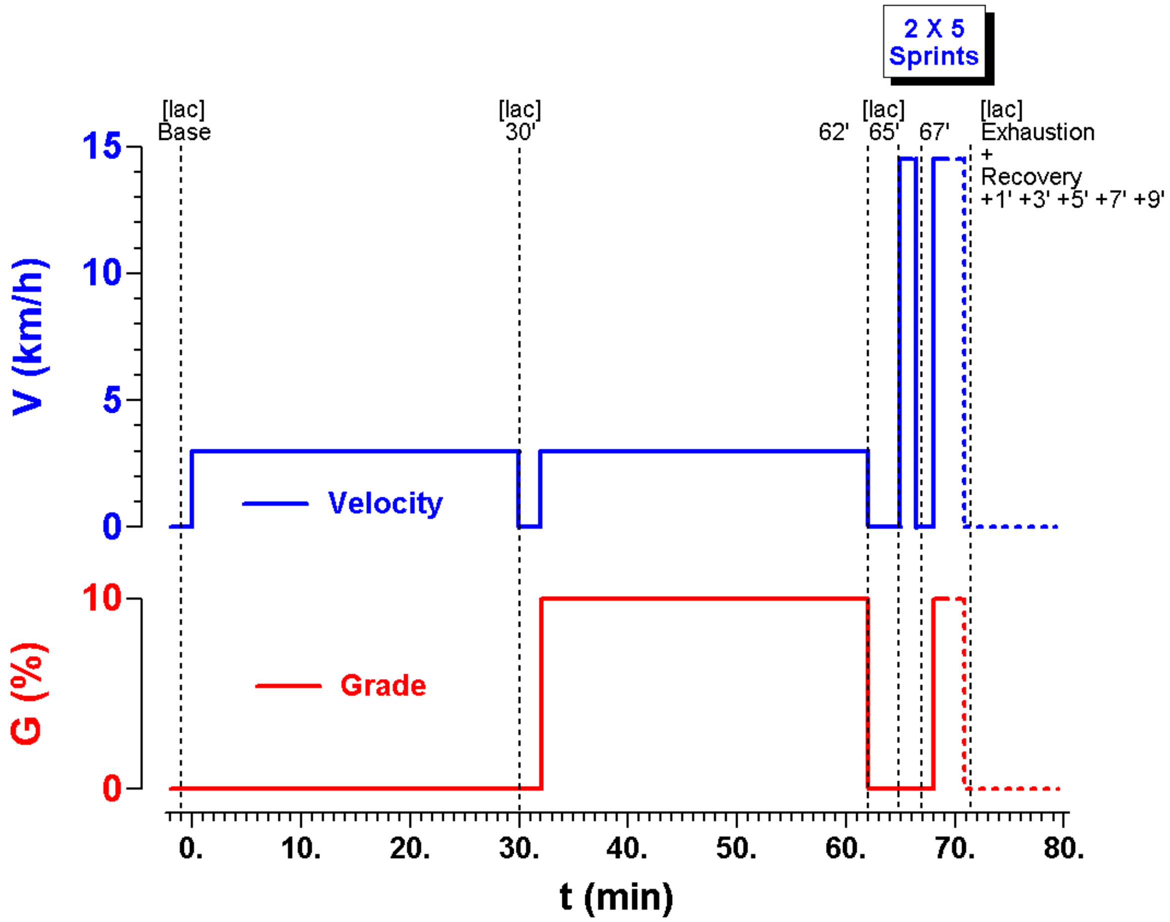

Figure 3: Diagram of the Load-March-Attack-Assault Test (LMAA-Test). Every test is carried out until exhaustion of the participant. Heart rate, oxygen uptake and ventilation are taken continuously while action, blood samples to determine lactate concentrations are taken at the marked moments. (V = Velocity; G = Grade, [lac] = Lactate concentration).

This pattern of demands reflects physical demands in typical mission tasks in a sufficiently realistic way: E. g. on a patrol soldiers have to march slowly for a prolonged period with their required equipment and, if ambushed, they may suddenly be involved in combat action (Figure 4). Statistical analysis of the heart rate clearly shows good agreement between results of the Field Tests and Load-March-Attack-Assault Test (Figure 5).

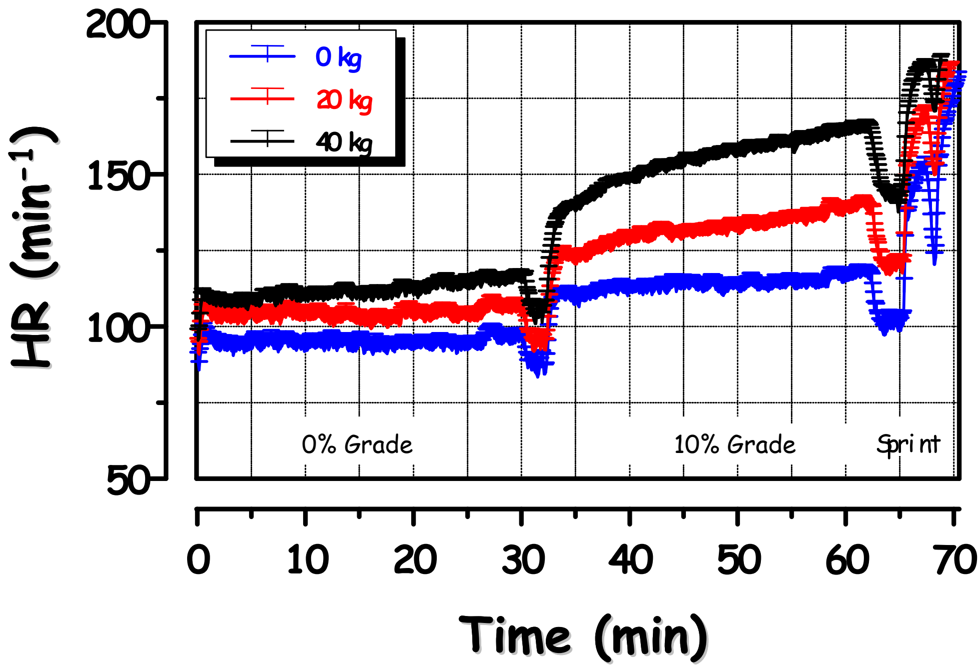

Figure 4: Heart rate tracings ($\overline{X}$ + standard error) during Load-March-Attack-Assault Test with loads of 0 kg (blue line), 20 kg (red line) and 40 kg (black line).

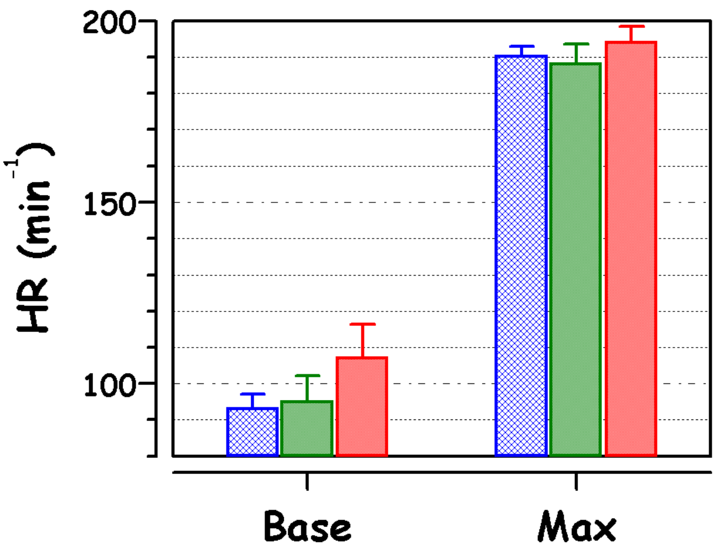

Figure 5: Mean baseline heart rates (Base) immediately before and mean maximal heart rates (Max) of exercise period. Blue column Load-March-Attack-Assault Test with field uniform and 40 kg load, green column Field Test (Antitank specialist 35 kg) and red column (Machine gun 51 kg).

The introduced complex test battery enables us to quantify physical strains of characteristic military tasks under standardized conditions in order to objectively distinguish between different equipments. However, the used methods allow no assessment of the influence of stressors on mental performance. Against this background we also integrated psychological test procedures in order to assess the impairment of mental capabilities during mission.

3.2 Mental requirements

Beside the physical abilities the mental capabilities are of outstanding significance for mission performance. Heavy loads or electronic equipment (C4I) may impair perception or intellectual faculties and may thus cause fatal errors. In order to assess the influence of clothing and individual equipment on required mental qualities we integrated various psychological test procedures that examine perception, short-term memory and cognition. All tests are computer-based and are presented on a screen in front of the treadmill (Figure 4). Results are recorded automatically by hitting one of the three coloured response buttons (blue, yellow, red) in front of the participant (Figure 6). All subjects had to complete a standardized learning and familiarisation programme in order to minimize effects of learning in the real test runs. In addition, every session has a different test configuration to avoid influences by repetitions.

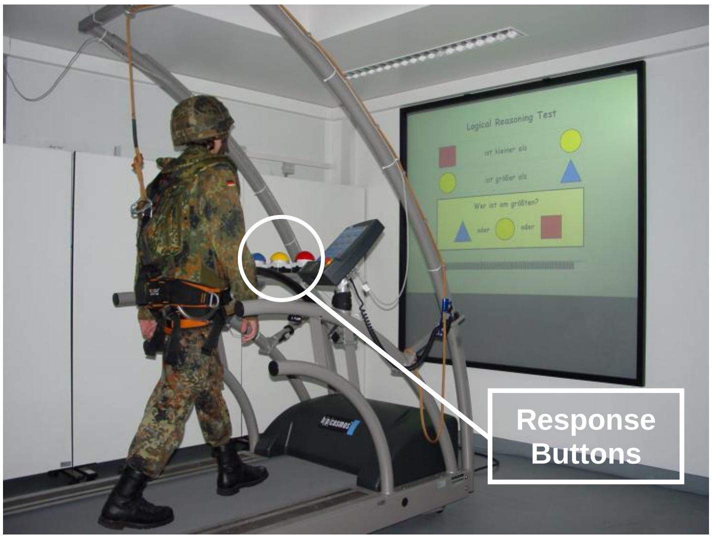

Figure 6: Experimental set-up during the first march phase ("Plain"). The three different coloured response buttons are mounted in front of the participant.

3.2.1 Observation Test

Visual reconnaissance is a typical military mission task of exceptional importance on patrols, marches or at checkpoints. In order to analyze and to compare the influence of different demands on visual perception and reaction we developed the observation test.

The test reproduces essential elements of observation tasks in simplified and standardized form. A defined number of critical stimuli are presented at different positions on two background pictures with different levels of difficulty in irregular intervals (Figure 7). Stimuli appear on a screen in a size of 1 x 1 pixels continuously increasing to a maximum size of 24 x 24 pixels. The task is to detect the stimulus as soon as possible and to confirm its presence by pressing the yellow response button. The timeframe for

recognition is limited to 15 s for each stimulus. Total testing time per session including a 30 s break between the two backgrounds amounts approximately 630 s (2 x 13 stimuli). The recorded results are number of correctly recognized stimuli, number of not recognized stimuli and reaction time.

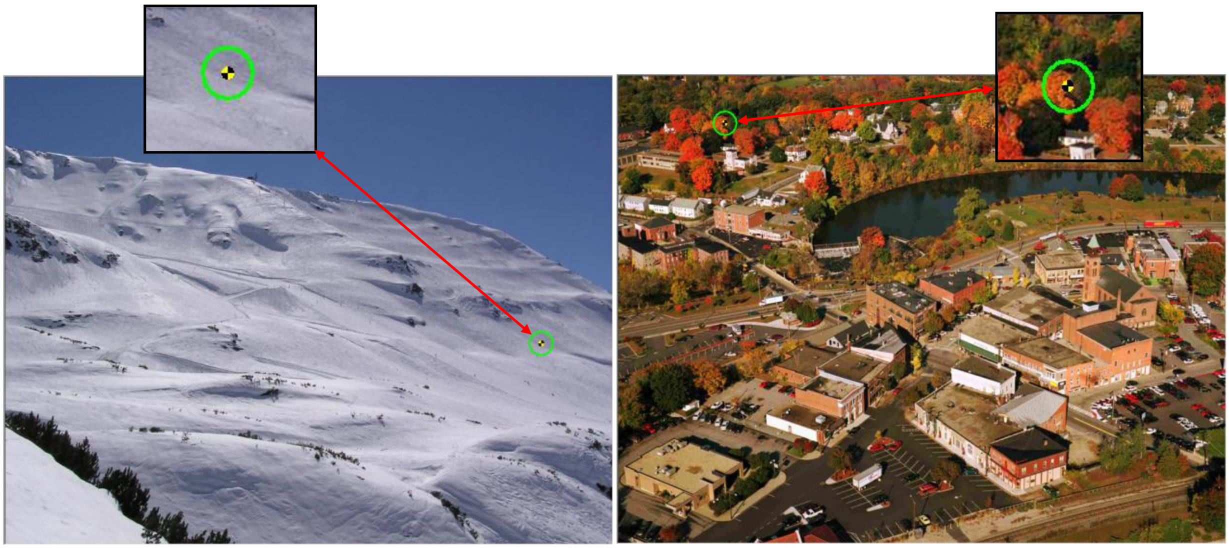

Figure 7: Observation Test: Examples of the stimuli on two different background pictures. The green circle around the stimulus indicates that it was correctly recognized.

3.2.2 Short-term memory Test

On duties at checkpoints or on patrols faces from a crowd are supposed to be scanned and checked against a target picture, for example from a passport, within a limited timeframe often lasting only a few seconds. To replicate this short term memory taxing task under controlled conditions, we derived a testing procedure from Sternberg's original test. To account for the dissimilar physiological structures involved in the processing of faces and for more relevance to real-world applications we replaced numbers or geometrical figures by faces (Leyk et al. 2008).

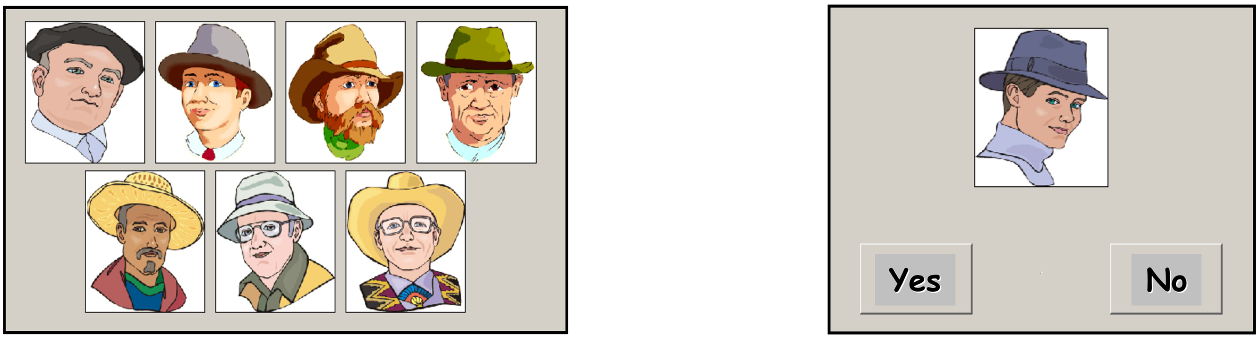

Figure 8: Short-term memory Test: Example of memory set (portraits) and one control item. By clicking the respective response button the participant is able to answer whether the control item has or has not been part of the seven previously presented faces.

A single test run begins with the presentation of a set of seven portraits for memorisation (Figure 8). All sets are matched for similar features (hair colour, facial hair, age gender etc.) to minimise the possibility of superficial recognition on the basis of global characteristics. The pictures are displayed with a grey background for either a 'short' (1.5 s) or a 'long' (4.5 s) period. After presentation, the screen is greyed out for a defined interval (1 s). A single face is displayed for 4 s as first control item followed by a 2-s intermission with a blank, grey screen. A second control item is then presented for another 4 s. During both presentation periods, the volunteers has to decide whether the respective control item has or has not been part of the seven faces previously presented by clicking the 'Yes' (blue) or 'No' (red) button. A single run took 24 s in total for the 'short' and the 'long' presentation period. The complete test is comprised of 10 runs in both the 'short' and the 'long' condition respectively. Total testing time amounts approximately 480 s (2 x 10 runs at 24 s each). Faces are presented only once per test set. Obtained performance parameters are the number of correct responses and corresponding response latencies.

3.2.3 Logical-reasoning Test

The ability to process given information, make decisions and act within a short period is another important capability in any mission. To assess stress-induced influences on reasoning the following test was defined and applied.

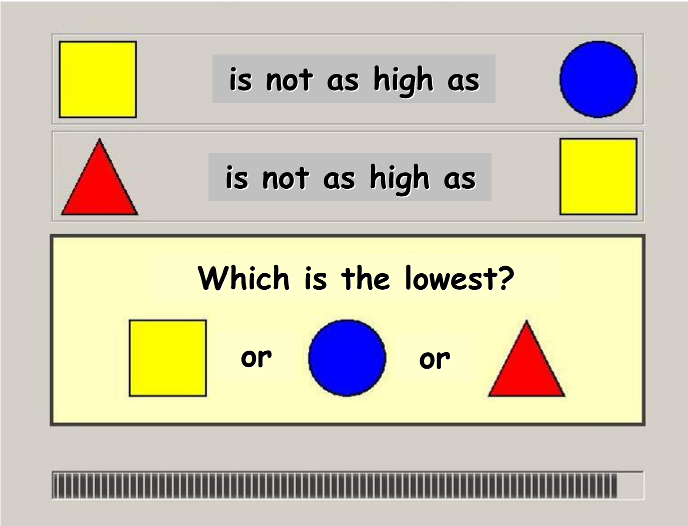

Figure 9: Logical-reasoning Test: Example of a task. The yellow field contains the question concerning the grammatical-semantic context above. The grey indicator below presents the running progress bar.

Three coloured geometrical shapes (blue circle, yellow square, red triangle) are put into a logical relation within a grammatical-semantic context. The task is to correctly identify this relationship and to answer the question in the yellow field below (Figure 9) by clicking the respective button as quick as possible. The maximum response time is 30 s, indicated by a progress bar on the bottom. After every answer or after passing the time limit the next query follows automatically. Total testing time amounts to 180 s.

Performance indicators are number of correct answers, number of incorrect answers and number of missed tasks as well as processing time of correct and incorrect responses. Figure 10 shows an example for the effects of different loads and march conditions on results of the Logical-reasoning Test.

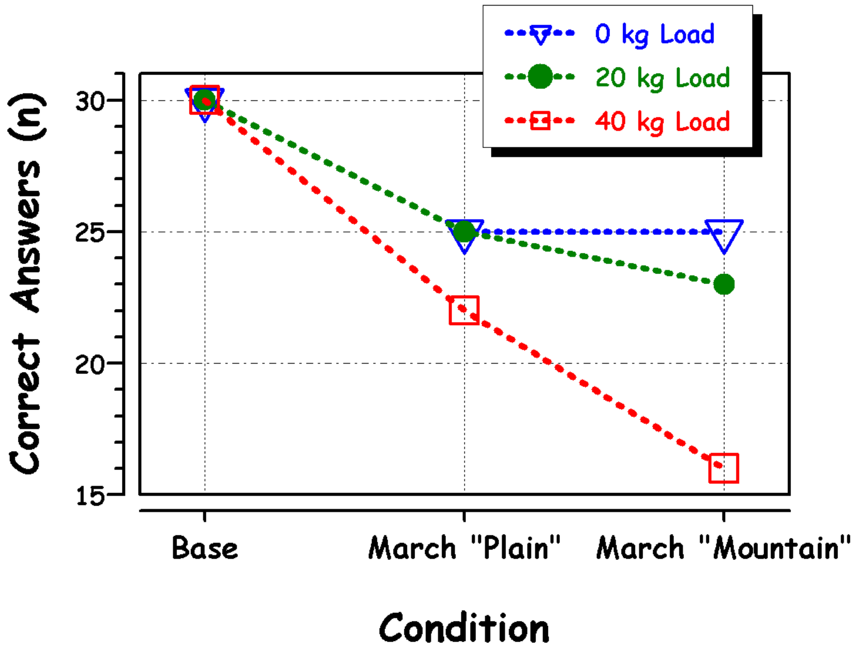

Figure 10: Example for the effects of different loads and march conditions on results of the Logical-reasoning Test.

3.2.4 Test Battery Procedure

Table 2 shows the sequence of the entire psychological test procedures during the LMAA-Test.

LMAA-Test Phase	**Test**	Phase (s)	Velocity (km/h)	Grade (%)
	Base	120	0	0
March 1 "Plain"	Video Presentation	450	3.0	0
	Time buffer	30	3.0	0
	Observation Test Picture 1 (including break)	330	3.0	0
	Observation Test Picture 2	300	3.0	0
	Short-term Memory Test 1.5 s	240	3.0	0
	Short-term Memory Test 4.5 s	240	3.0	0
	Logical-reasoning Test	180	3.0	0
	Time buffer	30	3.0	0
Interruption 1		120	0	10
March 2 "Mountain"	Video Presentation	450	3.0	10
	Time buffer	30	3.0	10
	Observation Test Picture 1 (including break)	330	3.0	10
	Observation Test Picture 2	300	3.0	10
	Short-term Memory Test 1.5 s	240	3.0	10
	Short-term Memory Test 4.5 s	240	3.0	10
	Logical-reasoning Test	180	3.0	10
	Time buffer	30	3.0	10
Interruption 2		180	0	0
Sprint "Plain"		120	14.5	0
Interruption 3		60	0	10
Sprint "Mountain"		608	14.5	10
Recovery		600	0	0

Table 2: Detailed sequence of the different psychological tests during LMAA-Test

3.3 Summary and Outlook

The described steps demonstrate our approach to the development of a new lab-based performance test battery that is determined to assess influences of clothing and equipment on human factors. With the LMAA-Test we are able to tax in sufficiently realistic way both physical and mental capabilities under standardized laboratory conditions. Actually, it will be used as standard evaluation tool to detect strengths and weaknesses of the introduced German Future Soldier System (Infanterist der Zukunft - Basis System) as compared to the prototype of the new German Future Soldier System (Infanterist der Zukunft -

Expanded System). Furthermore, the modular character of the test battery allows depending on the question to exchange sub-tests or to vary environmental conditions. So it is planned to extend the set-up in future and to test also influences of heat, cold or height in a simulation chamber.

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NOTA